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[Article]

Single- versus Multiple-Pass Boat Electrofishing for Assessing Smallmouth Bass Populations in Virginia Rivers

JOHN ODENKIRK*

Virginia Department of Game and Inland Fisheries, 1320 Belman Road, Fredericksburg, Virginia 22401, USA

SCOTT SMITH

Virginia Department of Game and Inland Fisheries, 1132 Thomas Jefferson Road, Forest, Virginia 24551, USA

Abstract.—A depletion electrofishing study was conducted on two Virginia rivers to estimate the density and biomass of smallmouth bass *Micropterus dolomieu*. Population estimates generated by a maximum likelihood analysis (MLM) were compared with those derived by the Leslie method. Also, population size structures from depletion samples were compared with those from single-pass surveys. Adult smallmouth bass were successfully depleted in three to five runs at most sites, and estimates averaged 386/km (SE = 132) and 47/ha (SE = 17) on the Rappahannock River and 265/km (SE = 90) and 38/ha (SE = 20) on the James River. Age-0 population estimates averaged 221/km (SE = 60) and 28/ha (SE = 14) on the Rappahannock River and 248/km (SE = 88) and 31/ha (SE = 14) on the James River. Capture probability was highest (mean = 0.40) for adult bass on the Rappahannock River and lowest (mean = 0.17) for age-0 bass on the James River. Population estimates based on the Leslie method, which regressed catch per effort on cumulative catch (lagged for one run), were greater than those generated by MLM, but the differences were relatively consistent and averaged 25%. Single-pass runs provided biased estimates of size structure at two of four Rappahannock River sites based on total length comparisons of stock size fish and structural indices (more large fish were captured by depletion electrofishing); however, little size selectivity bias existed between methods on the James River. This study suggests that smallmouth bass densities can be successfully estimated from sample reaches within large Virginia rivers and provides cautious optimism that single-pass electrofishing adequately describes smallmouth bass population size structure in some Virginia rivers.

Electrofishing is commonly used to evaluate fish populations (Reynolds 1996), and black bass *Micropterus* spp. electrofishing catch rates have been related to population densities (Hall 1986; Coble 1992). Electrofishing is also routinely used to evaluate population size structure (Paragamian 1984; Smith and Kauffman 1991); however, electrofishing may give biased estimates of size structure due to size selectivity (Twedt et al. 1992) and seasonal variation in catch (Carline et al. 1984; Sammons and Bettoli 1999). Additionally, electrofishing can displace fish from holding areas, or microhabitats, decreasing their vulnerability to capture (Bain et al. 1985).

Multiple-pass or depletion electrofishing may be necessary to better evaluate the adequacy of single-pass electrofishing (Meador et al. 2003). Low capture rates of older (larger) fish have been documented in population studies of smallmouth bass *M. dolomieu* (Roell and Orth 1993; Waters et al. 1993). Depletion electrofishing may result in a better estimation of true population size structure due to increased chances of capturing larger, less abundant individuals.

Depletion is also one method to determine density (Ricker 1975; Van Den Avyle 1993) and has been used to estimate biomass of several species of freshwater sport fish including brook trout *Salvelinus fontinalis* (Moore et al. 1983) and largemouth bass *M. salmoides* (Maceina et al. 1995). However, managers must exercise caution when estimating density and biomass based on depletion or removal counts because assumptions of a closed population, constant fishing effort, and constant probability of capture may be violated (Riley and Fausch 1992). Additionally, depletions (or removal-based population estimates) are likely to be biased by variable fish capture efficiencies contingent upon biotic and abiotic factors (Peterson et al. 2004).

Smallmouth bass are an important component

* Corresponding author: john.odenkirk@dgif.virginia.gov

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of Virginia's black bass fishery, which is the state's most popular sport fish category (USDI 1998). Biologists with the Virginia Department of Game and Inland Fisheries (VDGIF) routinely use single-pass daytime fall electrofishing surveys to determine smallmouth bass relative abundance and population size structure. Age is usually estimated from otoliths, and year-class strength, growth, and mortality are then estimated. Management recommendations (e.g., restrictive harvest length limits) are based on these data. Single-pass electrofishing is usually conducted because alternative methods (e.g., depletion electrofishing) are labor and time intensive; consequently, quantitative assessments of large lotic systems in Virginia are rare.

The study had several objectives: (1) determine if smallmouth bass could be successfully depleted from sample reaches within large Virginia rivers, (2) estimate smallmouth bass density and biomass, and (3) compare single-pass electrofishing with more intensive depletion electrofishing.

Methods

This study was conducted on the Rappahannock and James river systems in Virginia. The Rappahannock River has a watershed of 4,134 km^2 and an average annual discharge of 47 m^3/s. The James River has a watershed of 17,503 km^2 and an average annual discharge of 211 m^3/s. Both rivers drain the Blue Ridge and Piedmont physiographic provinces.

Depletion electrofishing was conducted at four sites in August 2001 on the Rappahannock River and five sites in September 2002 on the James River. Late summer was chosen for depletion electrofishing because we believed that low-water conditions would improve capture efficiency. Sample sites were either within or adjacent to reaches established for annual single-pass electrofishing and were near launch areas accessible to trailered boats. While not selected randomly, these sites were representative of habitat types given their dispersed locations, long lengths, and observations by Garman et al. (1991) that measured habitat parameters varied little in the James River. Sites encompassed a continuum of all habitat types observed (e.g., riffle–run–pool sequences). Site boundaries were selected based on the presence of natural barriers that would inhibit fish movement. These barriers were abrupt gradient drops of 30 cm or more. Block nets were not used due to logistical reasons. Rappahannock River sample sites averaged 283 m long, and average widths ranged from 46 to 162 m. James River sample sites averaged 734 m long, and average widths ranged from 50 to 165 m. Mean sample site areas on the Rappahannock and James rivers were 2.9 and 8.6 ha, respectively.

Rappahannock River sites were sampled with one of two configurations of DC electrofishing gear depending on channel morphology and width. The first configuration was used at the two upstream sites and consisted of a towed barge (Smith Root 2.5 GPP with three anodes) and four electrofishing johnboats. The towed barge was used at the upstream Rappahannock sites to better sample shallow shoreline margins but was not needed at the downstream (deeper) sites. Electrofishing boats ranged in size from 4.3 to 4.9 m, had double anode droppers, 5000-W generators and Smith Root Type VI-A pulse boxes. Each boat had a driver and two netters. The second configuration was used at the remaining two sites and consisted of six electrofishing johnboats. James River sites were sampled exclusively with electrofishing johnboats. Sampling began at downstream gradient barriers and progressed upstream, attempting to keep all gear in a straight line perpendicular to flow. Sample effort was quantified by physical site dimensions and by active electrofishing unit time from each boat. Captured fish were counted, measured (total length, mm; weight, g) and placed in live-cages downstream of sample sites after each run. Once three runs were completed, decisions were made concerning the need to continue sampling. These decisions were based on statistics derived from negative linear relationships between adult smallmouth bass catch and run. Depletion runs continued until regression statistics were deemed acceptable or a maximum of six runs was made. Acceptable regression statistics were set at P less than 0.10 for Rappahannock River sites but later modified to ''desirable'' r^2 values for James River sites. Desirable r^2 values were arbitrarily set at 0.80 or greater. The six-run maximum and r^2 limit were instituted based on manpower constraints, the need to complete sampling at all sites, and the requirement to have prompt criteria for terminating sampling at a given site. Four to seven runs appeared to be adequate to cause a significant decline in largemouth bass catch in reservoirs (Maceina et al. 1995), while Riley and Fausch (1992) recommended at least three passes when using removal electrofishing in trout streams. Fish were released following data collection on final runs.

Depletion data were analyzed using Microfish 3.0 which generates population estimates from re-

TABLE 1.—Catch of adult smallmouth bass by run, and statistics derived from simple linear regression of catch versus run. River codes are as follows: RAP = Rappahannock River; JAM = James River; R = run.

River	Site	Boats[a]	R1	R2	R3	R4	R5	R6	r^2	P
RAP	Embrey	6	17	12	8				1.00	0.04
	I-95	6	63	52	24	28	17		0.87	0.02
	Elys	5	55	25	21	4			0.91	0.05
	Phelps	5	21	16	7				0.97	0.10
JAM	Columbia	8	16	8	11	16	11	5	0.25	0.31
	Bremo	8	20	10	7				0.91	0.19
	Lynchburg	9	47	53	43	35	21		0.80	0.04
	Buchanan	7	86	79	52				0.90	0.21
	Lick Run	7	165	58	36				0.87	0.23

[a] Boats = number of electrofishing boats used, including tote barge at Elys and Phelps.

moval data based on the Burnham maximum likelihood estimation theory. Kulp and Moore (2000) used Microfish to estimate densities of rainbow trout *Oncorhynchus mykiss* in streams. Population estimates were generated for age-0 and adult smallmouth bass. Maximum age-0 sizes (120 mm on the Rappahannock River and 140 mm on the James River) were set based on several years of otolith evaluation from these rivers (VDGIF, unpublished data) and clear breaks in length-frequency distributions observed during sampling. Smallmouth bass that were not age 0 were assumed to be adults (age 1+). Biomass was estimated by adding individual fish weights recorded during sampling and then expanding bycatch–estimate differences using mean weight at each site. Population estimates from Microfish were then compared with those derived from the more widely publicized Leslie method (least squares linear regressions of catch per minute against cumulative catch at each site; Ricker 1975; Maceina et al. 1993). The assumptions of population estimation based on depletion criteria include: (1) no immigration or emigration, (2) equal probability of capture of all individuals, and (3) constant probability of capture among runs.

To determine whether single-pass electrofishing provided biased or incomplete representation of smallmouth bass size structure compared with depletion electrofishing, Rappahannock River depletion data (August 2001) were compared with single-pass data collected in October 2000 and 2001 (both data sets were available). James River depletion data (September 2002) were compared with single-pass data from October 2001 (fall 2002 sampling was not conducted). Single-pass samples involved one electrofishing boat and crew, as described above. Total lengths of stock size fish from depletion electrofishing were compared to fall single-pass electrofishing at each site using analysis of variance (ANOVA). Additionally, size structures from these data sets were compared using the proportional stock density (PSD) and relative stock density for fish of preferred length (RSD-P) (Gustafson 1988; Miranda 1993; Anderson and Neumann 1996). Sample sites within rivers were combined for comparisons of stock indices to increase sample size, and confidence intervals were calculated for PSD from formulas and tables provided by Gustafson (1988) and Miranda (1993). Confidence intervals were not calculated for RSD-P due to low numbers of preferred-size fish in samples.

Results

Adult smallmouth bass were successfully depleted in three to five runs on both rivers, although one site on the James River required six runs and still did not meet our arbitrary depletion criteria (Table 1). At two sites on the Rappahannock River, highly significant regressions ($P < 0.05$) were derived after only three electrofishing passes (negative relationships of adult catch versus run), while other sites on both rivers required four or five passes to produce acceptable statistics. Sites producing the best simple regression statistics (highest r^2 values with $P < 0.10$) with the least amount of effort were either higher in the watershed with narrower widths or characterized by low habitat complexity (e.g., vegetation, braiding).

Population density of adult smallmouth bass on the Rappahannock River varied from 167/km to 740/km (mean = 386/km; SE = 132) and 13/ha to 93/ha (mean = 47/ha; SE = 17; Table 2). Density of adult smallmouth bass on the James River varied from 50/km to 525/km (mean = 265/km; SE = 90) and 3/ha to 115/ha (mean = 38/ha; SE = 20). Population density of age-0 smallmouth bass on the Rappahannock River varied from 49/km to 327/km (mean = 221/km; SE = 60) and 10/ha to 70/ha (mean = 28/ha; SE = 14; Table 3).

TABLE 2.—Population estimates of adult smallmouth bass calculated with Microfish 3.0 and expanded for number of fish per kilometer and hectare. River codes are defined in Table 1. Means are given, with standard errors in parentheses.

River	Site	Number of runs	Catch	Estimate	95% confidence interval	P[a]	N/km	N/ha
RAP	Embrey	3	37	50	37–75	0.36	204	13
	I-95	5	184	225	194–256	0.29	740	49
	Elys	4	105	111	105–119	0.51	432	93
	Phelps	3	44	54	44–71	0.45	167	34
	Mean		93 (34)	110 (41)		0.40	386 (132)	47 (17)
JAM	Columbia	6	67	129	67–235	0.11	108	8
	Bremo	3	37	43	37–55	0.47	50	3
	Lynchburg	5	199	330	216–443	0.17	411	30
	Buchanan	3	217	413	222–604	0.22	231	32
	Lick Run	3	259	281	265–297	0.57	525	115
	Mean		156 (44)	239 (67)		0.31	265 (90)	38 (20)

[a] P = capture probability.

Density of age-0 smallmouth bass on the James River varied from 129/km to 596/km (mean = 248/km; SE = 88) and 8/ha to 82/ha (mean = 31/ha; SE = 14). Capture probability (P) was highest (mean = 0.40) for adult smallmouth bass in the Rappahannock River and lowest (mean = 0.17) for age-0 smallmouth bass in the James River.

Smallmouth bass biomass on the Rappahannock River averaged 69 kg/km and 8.6 kg/ha (SE = 21 and 3.4, respectively), while biomass on the James River averaged 66 kg/km and 9.3 kg/ha (SE = 20 and 4.8, respectively).

Leslie regressions of catch per effort against cumulative catch usually resulted in negative linear relationships, but these relationships were rarely significant (unlike many of the catch versus run regressions). Population estimates based on Leslie depletions were greater than those generated by Microfish (Table 4), but differences were generally consistent, and most sites differed by 28% or less. The two sites with the greatest differences had the lowest r^2, and one of these sites was the site that never met depletion criteria. Differences averaged 25% with the Columbia site omitted.

Comparisons between total lengths of stock size smallmouth bass from depletion electrofishing and single-pass electrofishing on the Rappahannock River suggested single-pass runs resulted in size selectivity at two of four sites (the presence of larger fish may have been underestimated by single-pass runs). While total length did not differ significantly at two sites, it was significantly greater for 2001 depletion sampling than for the 2000 single-pass sample. Also, total length at another site was significantly greater for depletion sampling than for the 2001 single-pass sample, taken only 2 months following depletion electrofishing (Table 5). Conversely, comparisons of James River smallmouth bass suggested little size selectivity existed between depletion and single-pass samples. At

TABLE 3.—Population estimates of age-0 smallmouth bass calculated with Microfish 3.0 and expanded for number of fish per kilometer and hectare. River codes are defined in Table 1. Means are given, with standard errors in parentheses.

River	Site	Number of runs	Catch	Estimate	95% confidence interval	P[a]	N/km	N/ha
RAP	Embrey	3	12	60	12–579	0.07	245	15
	I-95	5	54	80	54–121	0.20	263	17
	Elys	4	26	84	26–351	0.09	327	70
	Phelps	3	16	16	16–18	0.67	49	10
	Mean		27 (9)	60 (16)		0.26	221 (60)	28 (14)
JAM	Columbia	6	40	150	40–609	0.05	158	12
	Bremo	3	19	95	19–757	0.07	129	8
	Lynchburg	5	75	97	75–124	0.25	155	11
	Buchanan	3	138	384	138–812	0.14	596	82
	Lick Run	3	61	88	61–129	0.32	200	44
	Mean		67 (20)	163 (56)		0.17	248 (88)	31 (14)

[a] P = capture probability.

TABLE 4.—Comparison of population estimates of adult smallmouth bass calculated with two different methods: Microfish 3.0 and catch versus cumulative catch regressions (with associated coefficients of determination). River codes are defined in Table 1.

River	Site	Microfish	Regression	Difference (%)	r^2	P
RAP	Embrey	50	69	38	0.98	0.09
	I-95	225	338	50	0.41	0.24
	Elys	111	121	9	0.61	0.22
	Phelps	54	65	20	0.89	0.22
JAM	Columbia	129	2,114	1,539	0.00	0.70
	Bremo	43	49	14	0.94	0.11
	Lynchburg	330	438	33	0.49	0.13
	Buchanan	413	547	32	0.98	0.02
	Lick Run	281	281	0	0.90	0.11

only one site (20%), total length was significantly greater for fall 2001 than for 2002 depletion sampling (Table 6).

Rappahannock River smallmouth bass stock indices (PSD and RSD-P) from depletion electrofishing and single-pass electrofishing varied between years (Table 7). Based on these descriptors, population size structure was similar between depletion electrofishing in 2001 and single-pass sampling in 2000 (PSD of 16 and 17; RSD-P of 5 and 5). However, in 2001; single-pass PSD was 11, and RSD-P was 1. Stock index comparisons of James River smallmouth bass suggested minimal bias between depletion and single pass electrofishing (PSD of 25 and 26; RSD-P of 8 and 7; Table 8).

Discussion

Adult smallmouth bass can be successfully depleted from sample reaches within large Virginia rivers. Although the upper tier of sampling effort included five electrofishing passes with nine boats, desirable outcomes were achieved with less effort (several sites on both rivers were depleted with three runs and five to seven boats). The resulting population densities were similar, ranging from a mean of 38/ha in the James River to 47/ha in the Rappahannock River. Biomass (adults + age 0) averaged 8.6 and 9.3 kg/ha in the Rappahannock and James Rivers, respectively. The James River estimate was very similar to the only other known estimate from Virginia. Garman et al. (1991) estimated mean smallmouth bass biomass at 9.9 kg/ha at seven James River sites during a 4-year study utilizing detonating cord.

Population studies, including mark–recapture and catch depletion techniques, have been known to provide underestimates of true population size (Riley and Fausch 1992; Edwards et al. 1997), but estimates derived by catch depletion methods may have a lower bias associated with assumption violations than the mark–recapture studies (see Van Den Avyle 1993; DiCenzo and Garren 2001). For example, longer time intervals inherent in mark–recapture studies between the mark and capture events may allow for fish mortality and fish movement into or out of study areas. It is likely the minimal elapsed time between depletion runs and the presence of gradient barriers at each end of our study sites minimized this particular bias. Alternatively, it is possible that population estimates in the current study, derived from depletion methods, were subject to greater bias than mark–

TABLE 5.—ANOVA comparisons of mean total length (mm) of stock size smallmouth bass from 2001 depletion electrofishing (Depl.2001) and single-pass electrofishing (SP) from 2000 and 2001 at four sites on the Rappahannock River. Within sites, lengths with asterisks are significantly different ($P < 0.10$).

Site	Depl.2001	SP 2000	SP 2001	P	F	df
Embrey	248	232	256	0.79	0.34	2, 42
I-95	241	247	236	0.39	1.09	2, 313
Elys	245*	224*	227	0.09	2.22	2, 217
Phelps	251*	220	214*	0.01	4.16	2, 72

TABLE 6.—ANOVA comparisons of mean total length (mm) of stock size smallmouth bass from 2002 depletion electrofishing (Depl.2002) and 2001 single-pass electrofishing (SP) in 2001 at five sites on the James River. Within sites, lengths with asterisks are significantly different ($P < 0.10$).

Site	Depl.2002	SP 2001	P	F	df
Columbia	253	234	0.25	1.34	1, 81
Bremo	270	295	0.21	1.60	1, 59
Lynchburg	213*	233*	0.01	6.12	1, 157
Buchanan	269	249	0.31	1.05	1, 112
Lick Run	253	251	0.83	0.05	1, 225

TABLE 7.—Proportional stock density (PSD; 90% confidence interval [CI]) and relative stock density for fish of preferred length (RSD-P) of smallmouth bass with sample sizes from 2001 depletion electrofishing (Depl.2001) and single-pass electrofishing (SP) in 2000 and 2001 at four combined sites on the Rappahannock River.

Variable	Depl.2001	SP 2000	SP 2001
PSD	16	17	11
90% CI	12–20	12–22	6–16
RSD-P	5	5	1
N	228	163	132

TABLE 8.—Proportional stock density (PSD; 90% CI) and relative stock density for fish of preferred length (RSD-P) of smallmouth bass with sample sizes from summer 2002 depletion electrofishing (Depl.2002) and single-pass electrofishing (SP) in 2001 at five combined sites on the James River.

Variable	Depl.2002	SP 2001
PSD	25	26
90% CI	22–28	20–32
RSD-P	8	7
N	482	163

recapture studies. Peterson and Cederholm (1984) cautioned that mark–recapture estimates were as much as 8% more accurate than several removal techniques in estimating known populations of juvenile coho salmon *O. kisutch* in a small Washington stream and recommended at least 1 h of recovery time between runs. In our study, at least 2 h were usually allowed between runs while fish were processed. Riley and Fausch (1992) further investigated the phenomena of population underestimation by depletion sampling and found that decreasing capture probability in successive runs was a frequent problem when estimating trout abundance in small Colorado streams. The problem was most serious when capture probabilities were relatively low and when few passes were completed. Capture probability of adult smallmouth bass in the present study ranged from 0.11 to 0.57—arguably in the low to moderate range, but three to six passes were used. Mean capture probability of adult smallmouth was 0.40 in the Rappahannock River and 0.36 in the James River with the Columbia site omitted. According to Riley and Fausch's phenomena (1992), our estimates likely underestimated true population size.

Population estimates derived with the Leslie method were nearly always greater than those produced by Microfish, but the differences were relatively consistent (suggesting precision among techniques). Large sample areas likely exacerbated underestimation bias typically associated with depletion estimates and probably resulted in conservative estimates from both methods. Negative, but insignificant relationships produced by the Leslie method may have resulted because typically less than 85% of the estimated population was sampled. The total number of fish collected should exceed 85% of the estimated population (Mahon 1980; Maceina el al. 1993). To reach that percentage, we would likely have needed only one or two additional runs per site.

The third and final objective of this study was to compare annual single-pass electrofishing with depletion electrofishing, primarily the utility of the former to describe accurate population size structures from which management recommendations can be made. Inherent assumptions included that depletion sampling did, in fact, describe real population size structures with which to compare predepletion or postdepletion single-pass samples, and that size structures of the populations did not change between sample periods. Single-pass electrofishing has provided reliable indices of trout abundance (and accordingly, size structure) on small mountain streams but may be unreliable in larger streams or where complex habitat exists (Kruse et al. 1998). Comparisons between total lengths of stock size smallmouth bass (one surrogate for population size structure) indicated differences between rivers and sample methods, as mean depletion lengths were greater at 50% of the sites on the Rappahannock River but similar to mean single-pass lengths on the James River.

Rappahannock River data suggested a size bias occurred with single-pass sampling that underrepresented larger fish. Electrofishing typically selects for larger fish due to various collection biases (McClendon and Rabeni 1986; Reynolds 1996), so the nature of this bias in the present study is unclear. It is possible that larger fish may have been better able to avoid a single electrofishing boat during some single-pass samples but could not escape the gauntlet of boats during more intensive depletion sampling. However, this pattern was not consistent and could have been related to the modification of sample reaches to accommodate natural barriers and variations in habitat parameters (e.g., depth, velocity) that were not measured. Additionally, population size structure may have shifted between depletion and single-pass electrofishing, but this scenario was less likely on the Rappahannock River because 2001 depletion and 2001 single-pass sampling occurred only 2 months apart. Smallmouth bass population size structure should have remained relatively constant between sample periods due to limited movement, slow growth, and the persistence of strong year-classes through time (VDGIF, unpublished data). However, it is possible that a portion of the population sampled during depletion electrofishing experienced delayed handling mortality and thus impacted single-pass size structures on the Rappahannock River.

Differences in structural indices supported trends in average size between samples. The greatest difference occurred between Rappahannock River 2001 depletion and 2001 single-pass samples, but the consistency of the 2000 single-pass and depletion samples should not be dismissed. The difference in PSD between the former samples should have been detectable given the change of 55% and sample sizes involved (Miranda 1993). Delayed mortality, fish avoidance, or both (Cross and Stott 1975) resulting from depletion sampling only 2 months earlier may have impaired the catch of larger bass at Rappahannock River sites in fall 2001. James River samples suggested single-pass runs were as effective as depletion runs at catching larger fish and thus describing population size structure.

Future study will include efforts to gather additional density and biomass estimates from other rivers. This study provides cautious optimism that single-pass fall electrofishing surveys adequately describe smallmouth bass population size structure in some large Virginia rivers. However, further study is required to elucidate this relationship and should incorporate additional population estimation techniques such as telemetry, mark and recapture, and underwater observation.

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